



Status and Recent Results from LEUTL

Characterization of the Saturation of the APS SASE-FEL

John W. Lewellen for the APS SASE-FEL
Commissioning Team



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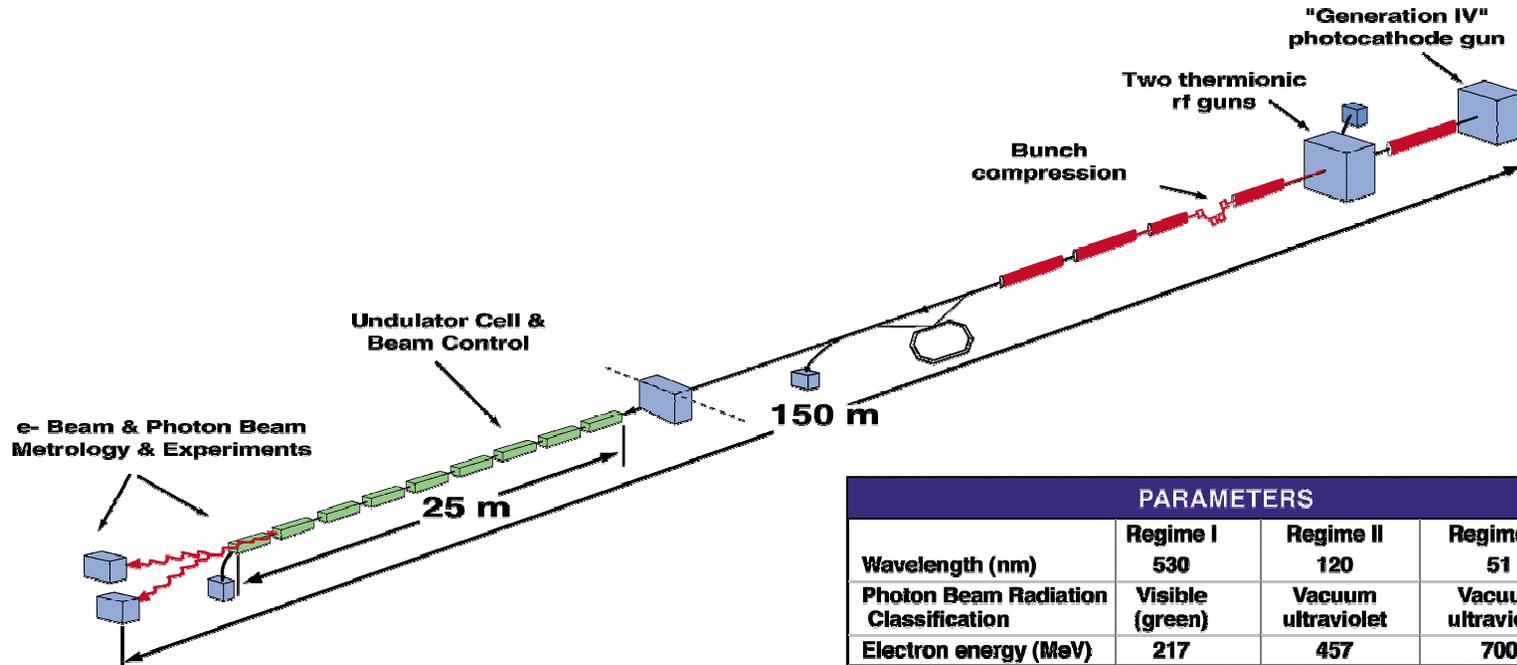


Outline

- Descriptions of the APS linac and SASE-FEL Undulator Line
- Diagnostics Capabilities
- Measurement Methodologies
- Selected Results
- Conclusions and Future Directions



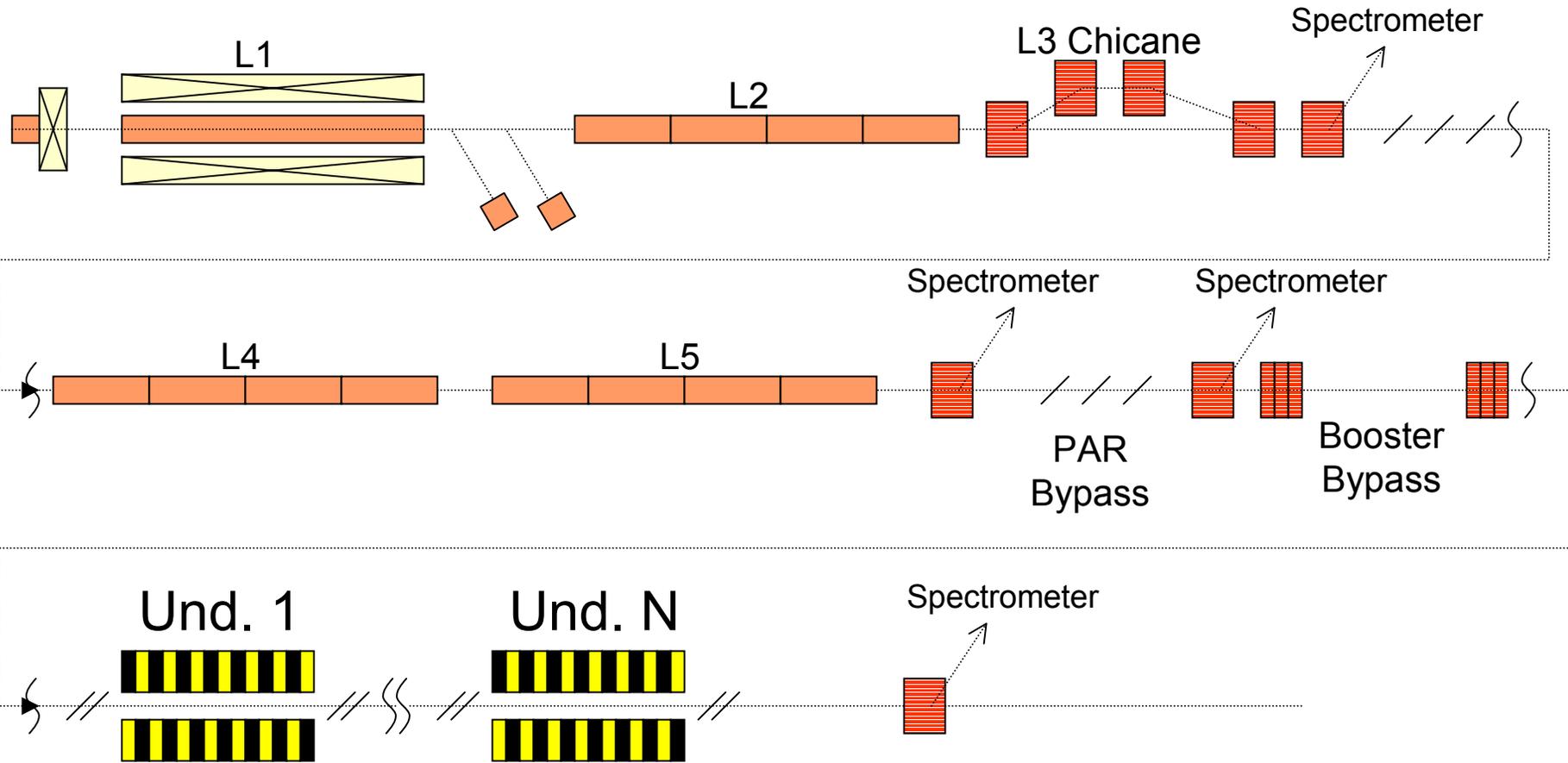
The APS SASE-FEL



PARAMETERS			
	Regime I	Regime II	Regime III
Wavelength (nm)	530	120	51
Photon Beam Radiation Classification	Visible (green)	Vacuum ultraviolet	Vacuum ultraviolet
Electron energy (MeV)	217	457	700
Normalized emittance (mm mrad)	5π	3π	3π
Energy spread (%)	0.1	0.1	0.1
Peak current (A)	100	300	500
Undulator period (mm)	33	33	33
Magnetic field (T)	1.0	1.0	1.0
Undulator gap (mm)	9.3	9.3	9.3
Cell length (m)	2.73	2.73	2.73
Gain length (m)	0.81	0.72	1.2
Undulator length (m)	9 x 2.4	9 x 2.4	10 x 2.4



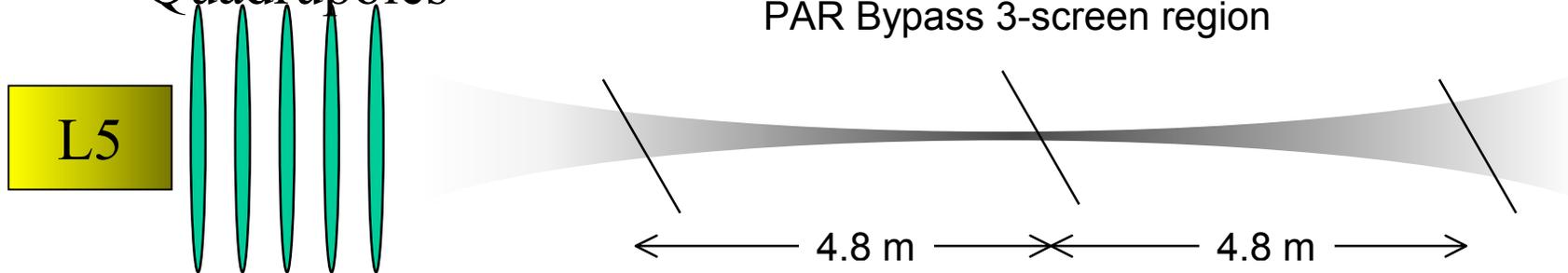
Linac Details





Emittance & Matching

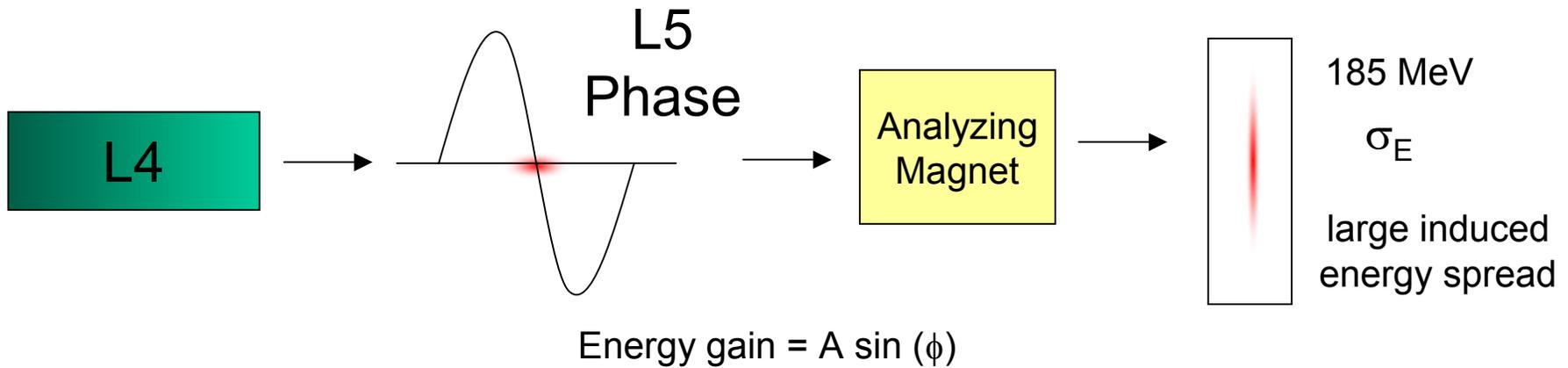
Quadrupoles



- Obtain the Twiss parameters
- Calculate mismatch: $\delta_m = \frac{1}{2}(\beta_o \gamma_m - 2\alpha_o \alpha_m + \beta_m \gamma_o)$
- Correct quadrupole strengths
- Repeat until $\delta_m \sim 1$



Bunch Length Measurement



$\Delta E \sim A \Delta\phi$ for small ϕ (near zero crossing)

$$\sigma_L = \frac{\sqrt{\sigma_E^2 - \sigma_s^2}}{A}$$

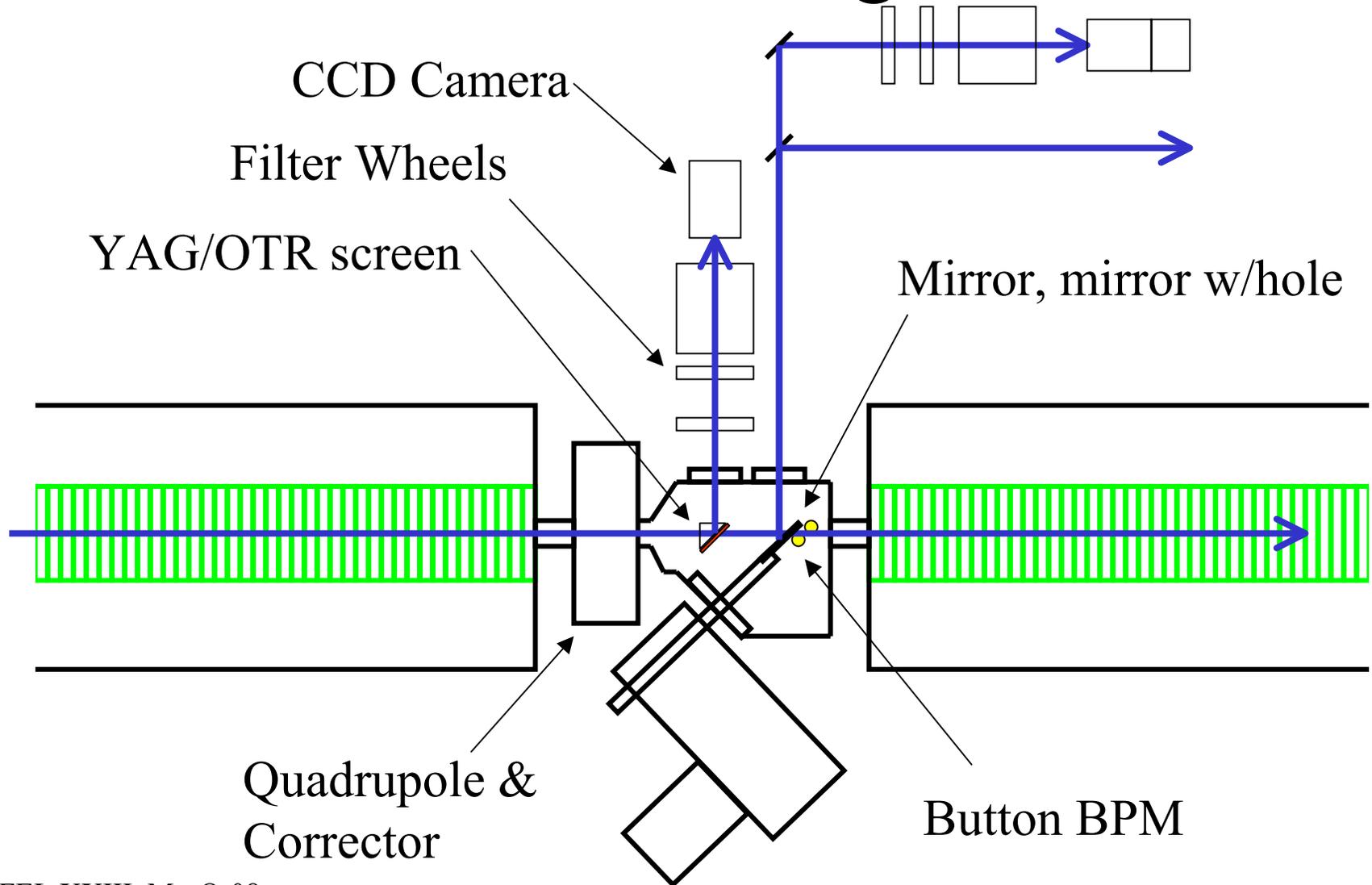


Undulator Line Details

Length	9 x 2.4 m
Period	3.3 cm
Gap	9.4 mm
Field	1 T
K	3.1
Intermodule gap	33 cm

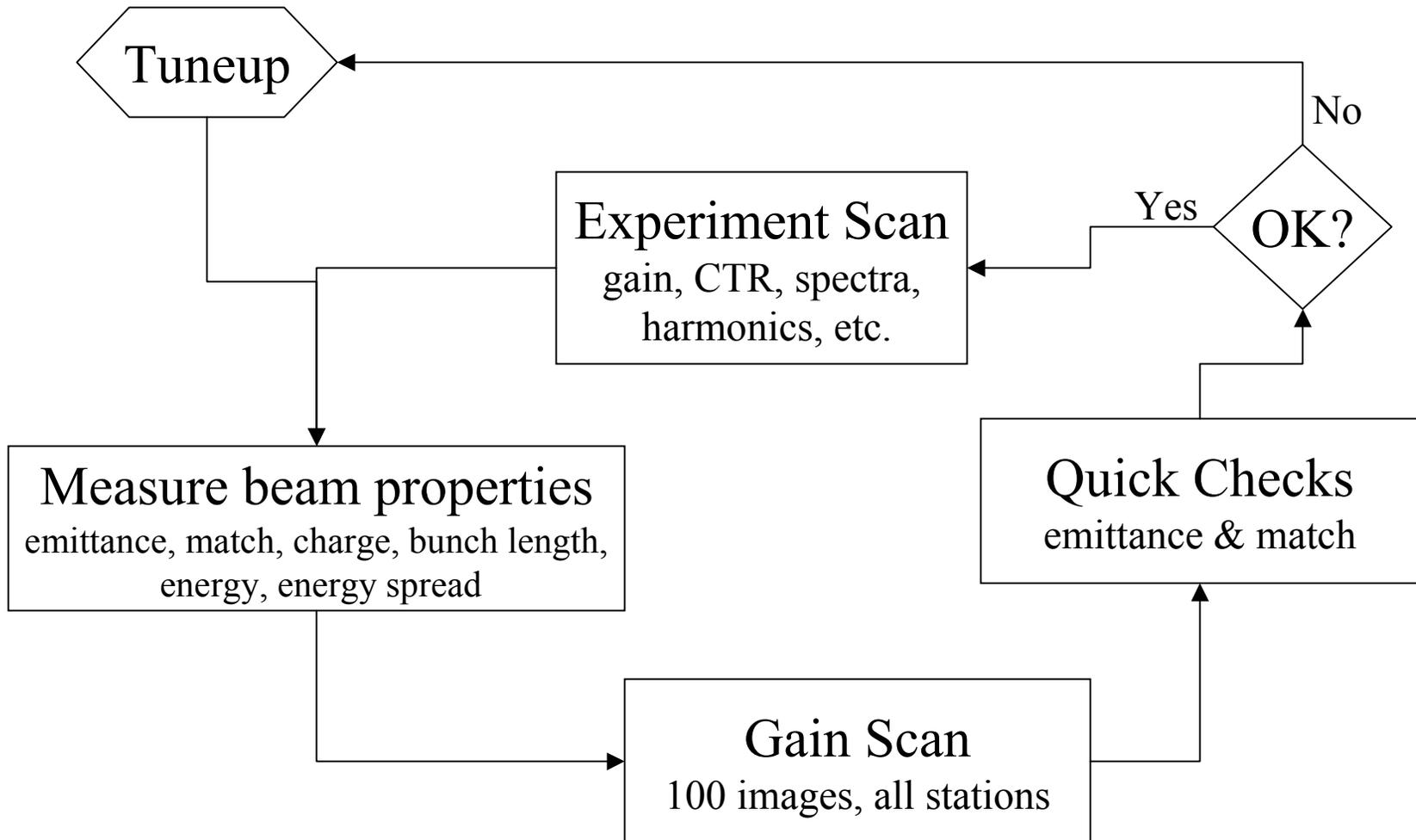


Undulator Line Diagnostics





Measurement Methodology



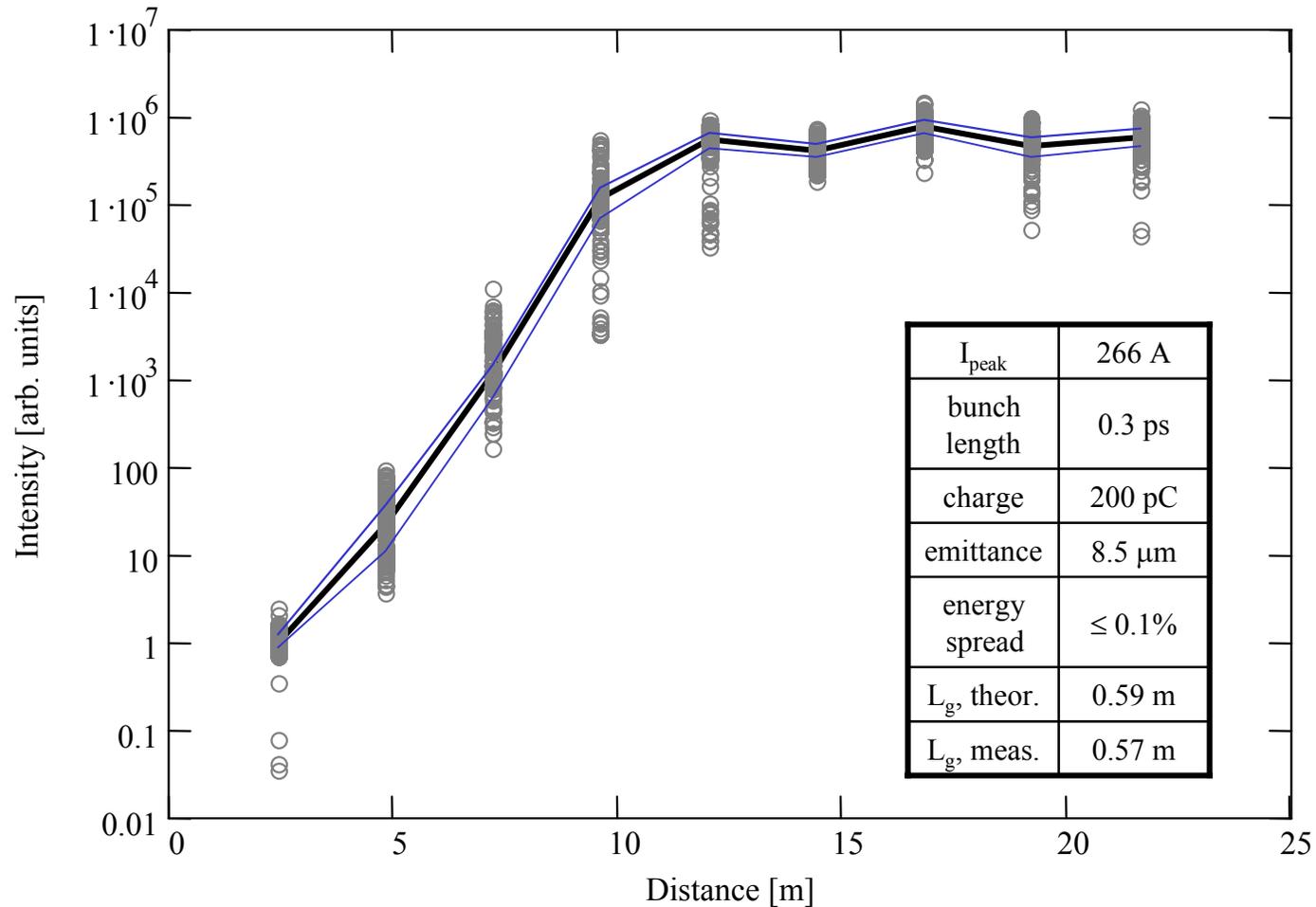


How Do We Know It Saturated?

- The gain curve rolls over and intensity stops growing
- Output power statistics differ
- Induced energy spread on electron beam becomes very large
- CTR intensity rolloff
- Spectrum narrows & changes

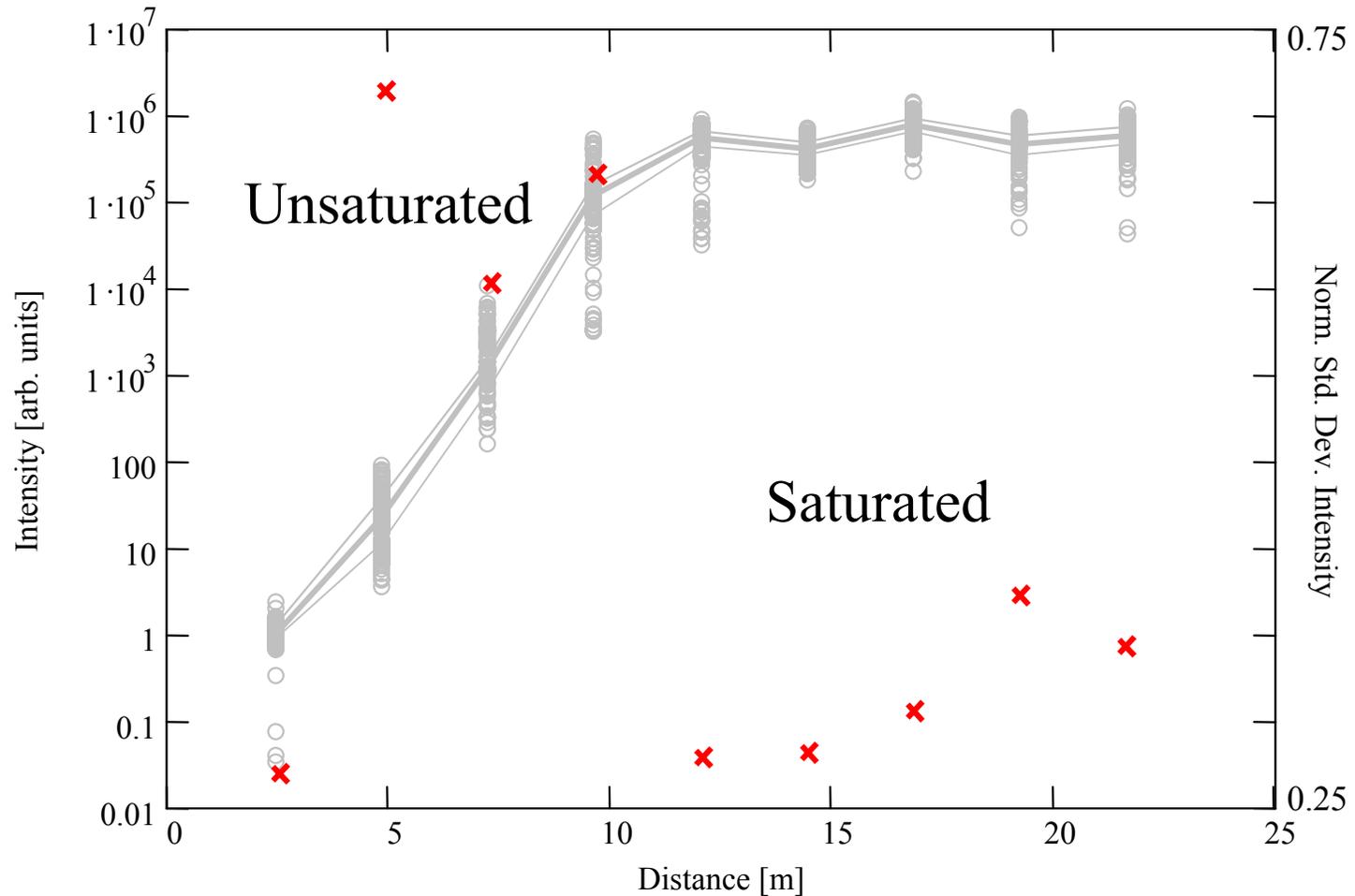


Optical Intensity Gain





Optical Intensity Statistics





SASE Spectra – 385 nm

VLD2 (4.8 m)

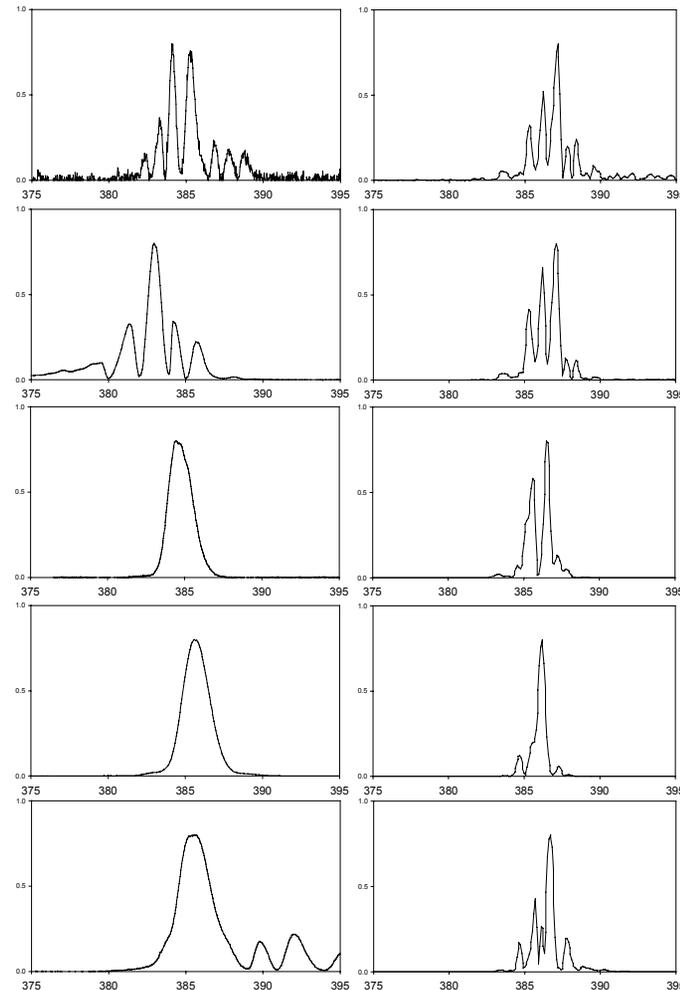
VLD3 (7.2 m)

VLD5 (12 m)

VLD7 (16.8 m)

VLD9 (21.6 m)

Single shot spectra



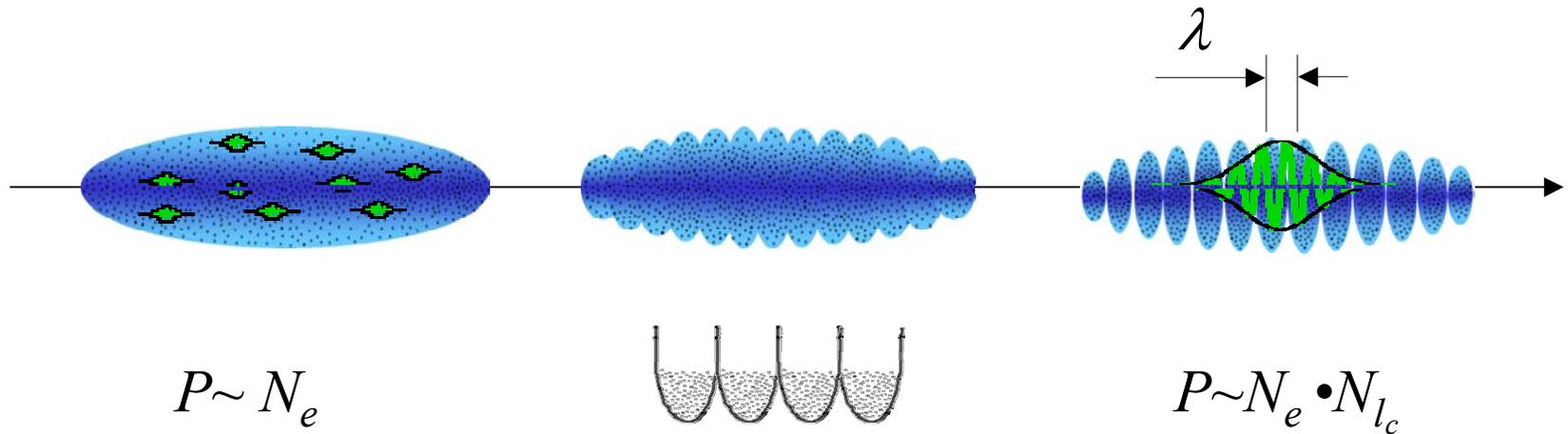


Electron Beam Spectrum

- Pierce parameter: ~ 0.004
- Incoming energy spread: $\leq 0.1\%$ rms
- Energy spread at end of undulator line:
 - no SASE saturation, $\leq 0.1\%$ rms, no fluctuations
 - SASE saturation, $\geq 0.5\%$ rms (beyond screen limits), and fluctuating dramatically



e-Beam Microbunching



P - Radiation Power

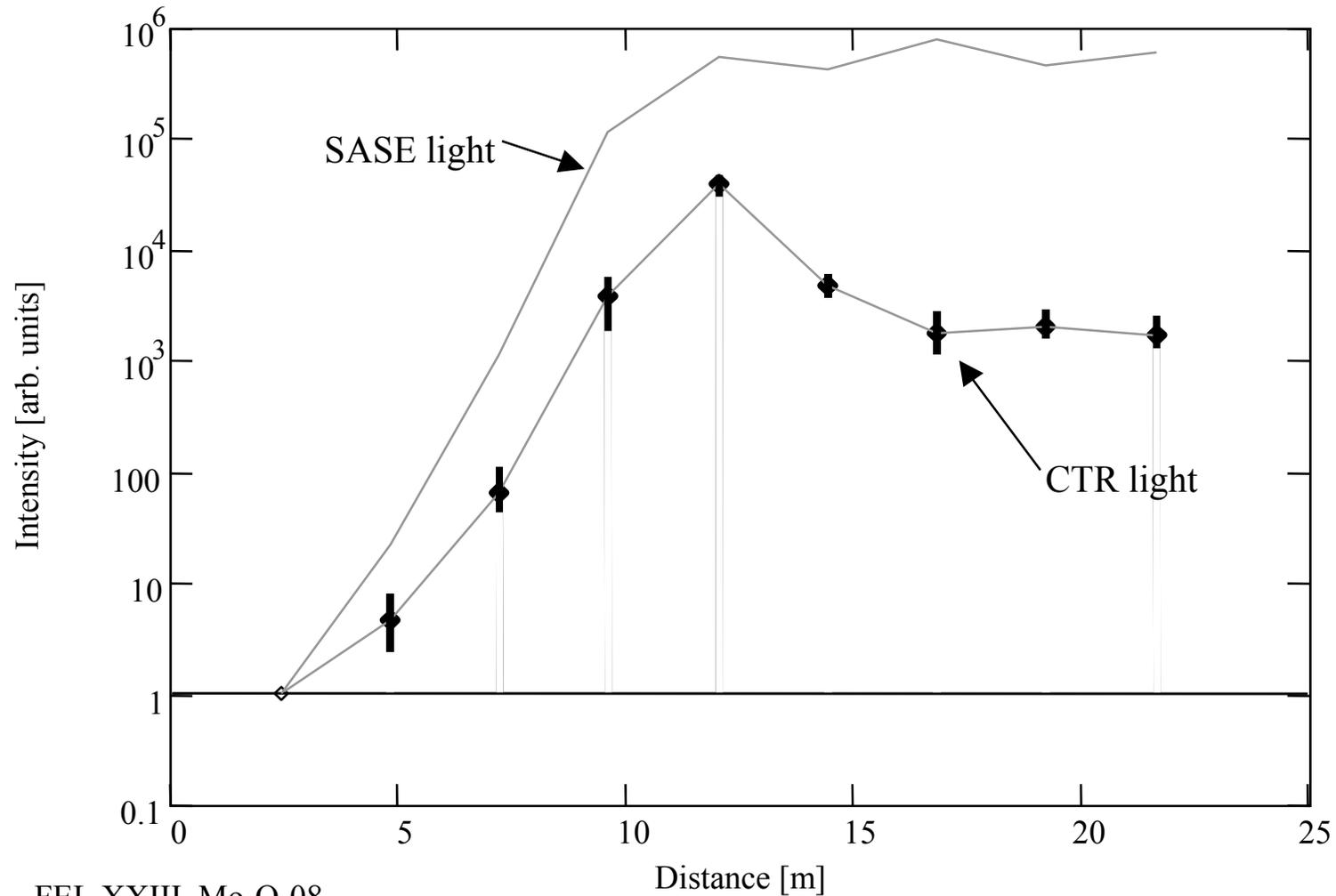
N_e - Number of particles
in the bunch

$E_u + E_R \Rightarrow \text{potential wells}$

N_{l_c} - Number of particles
in coherence volume

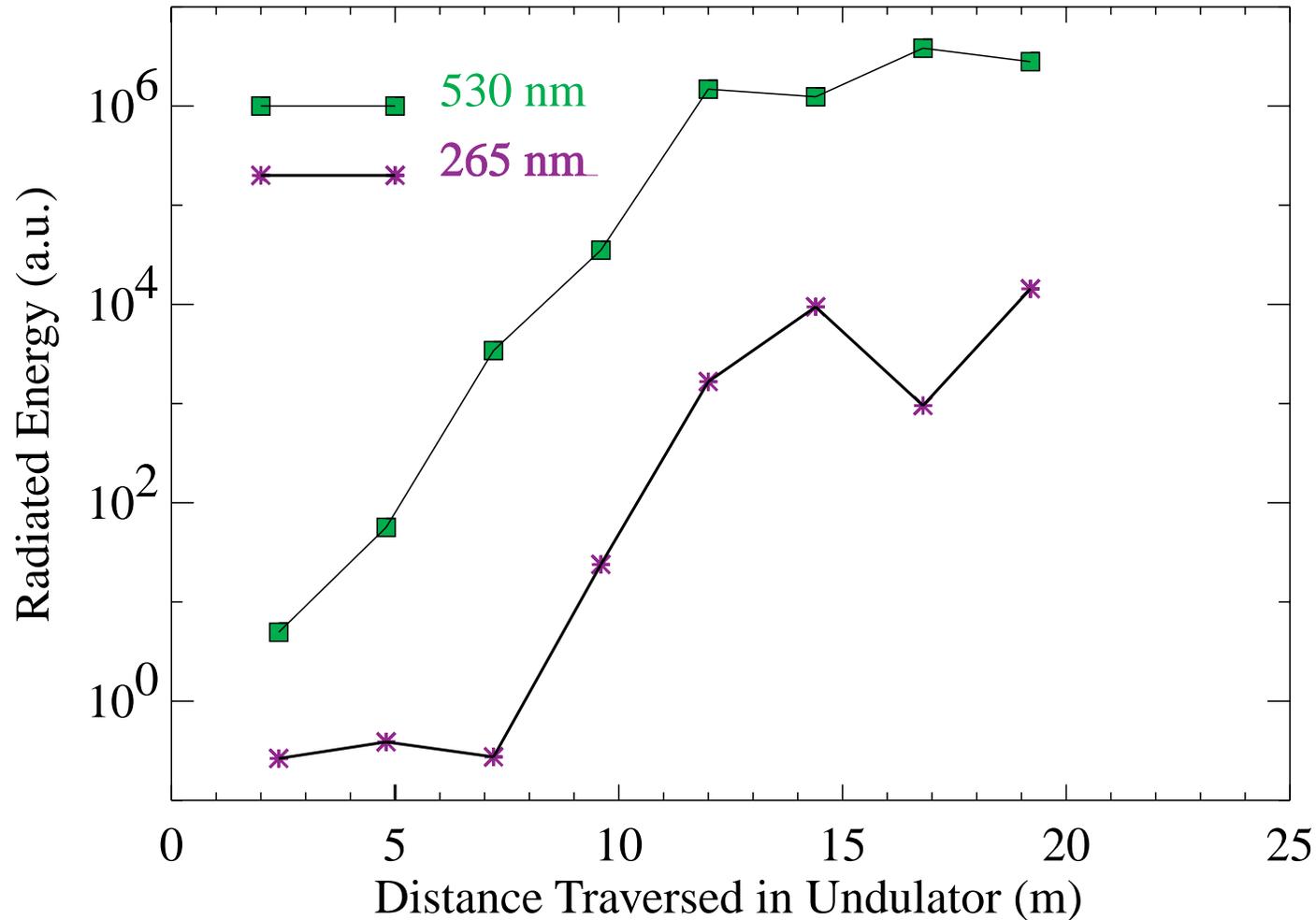


Microbunching Measurement



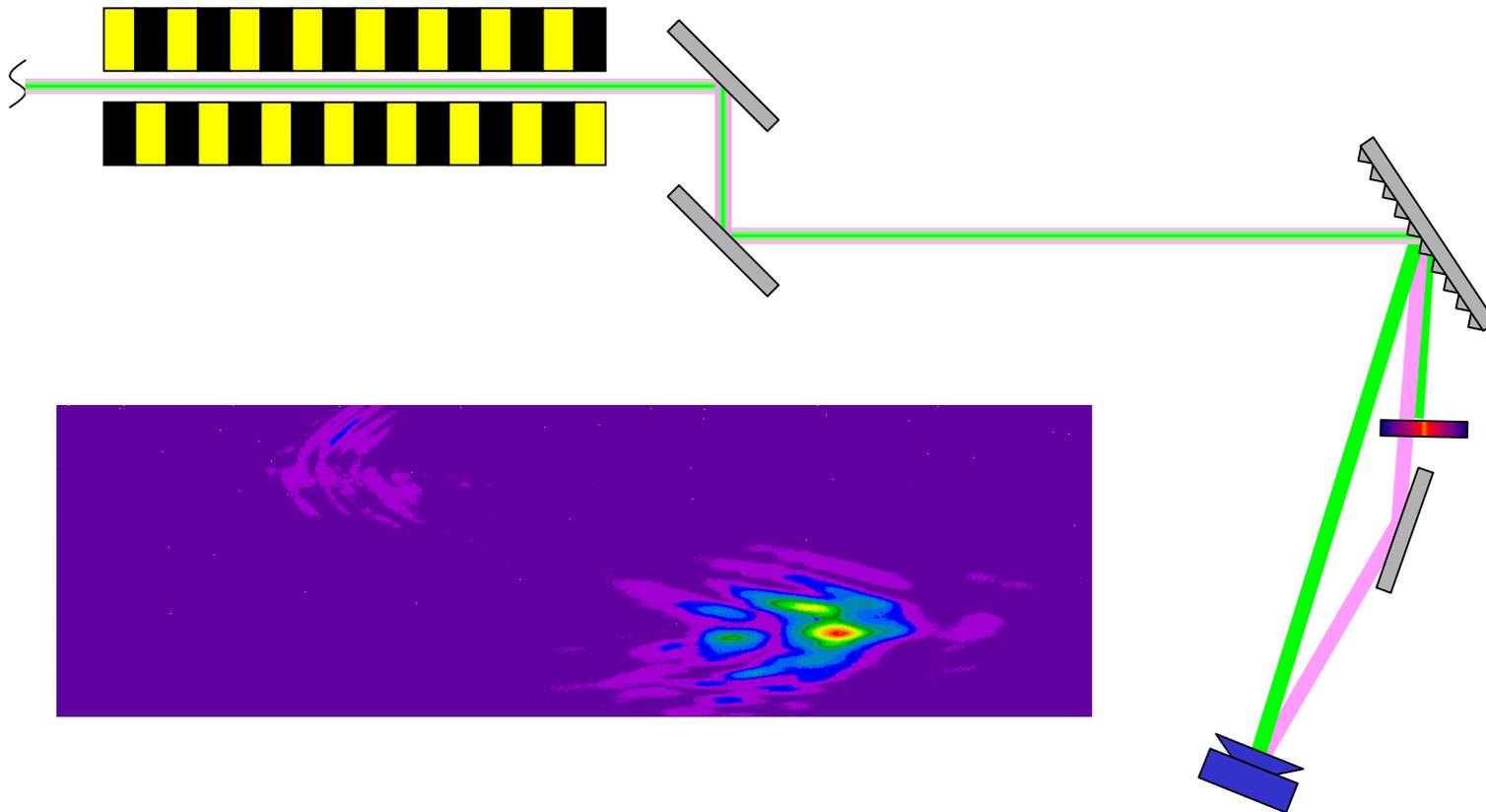


Second Harmonic Gain



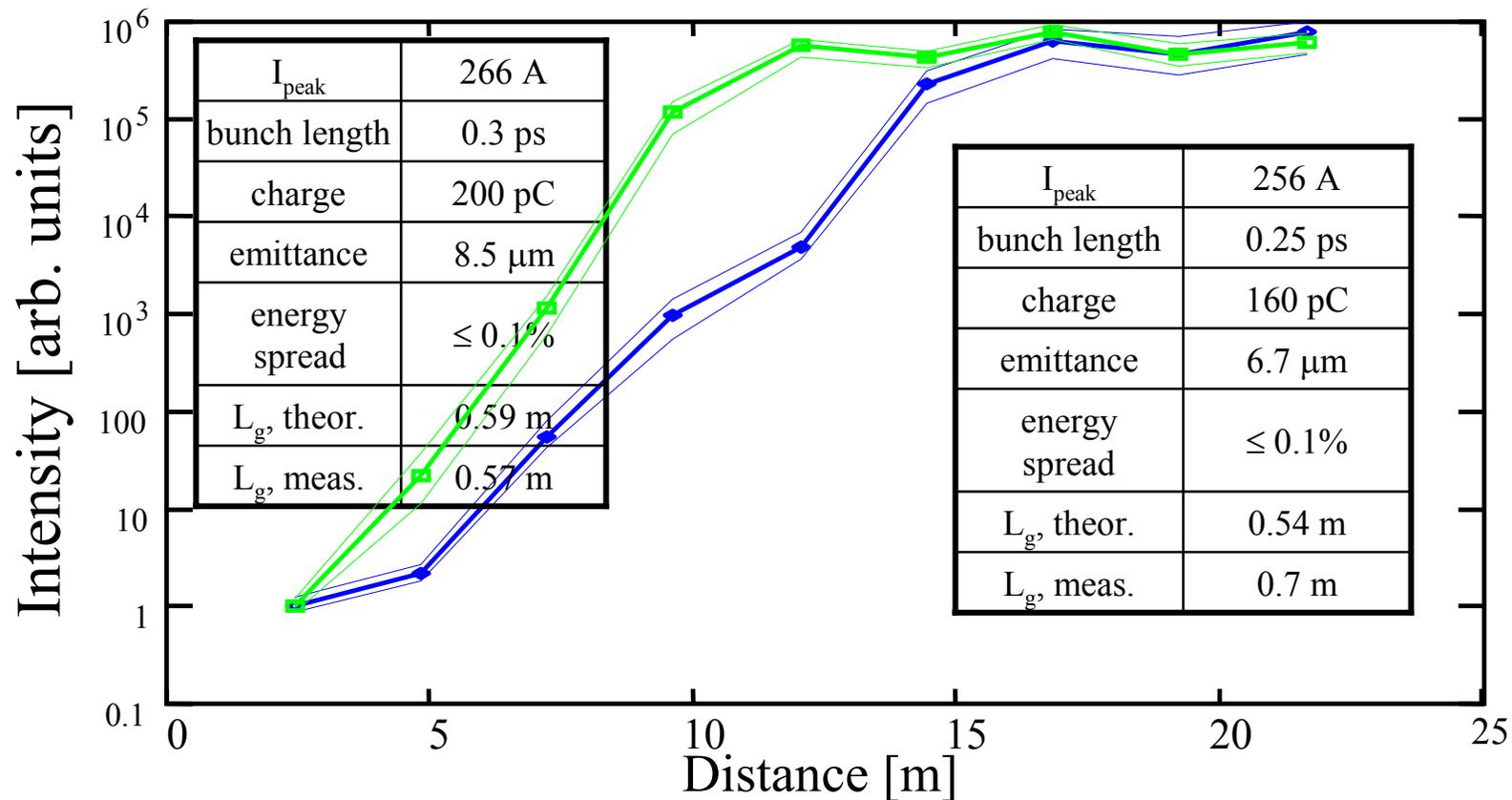


Simultaneous Spectra: Fundamental and 2nd Harmonic



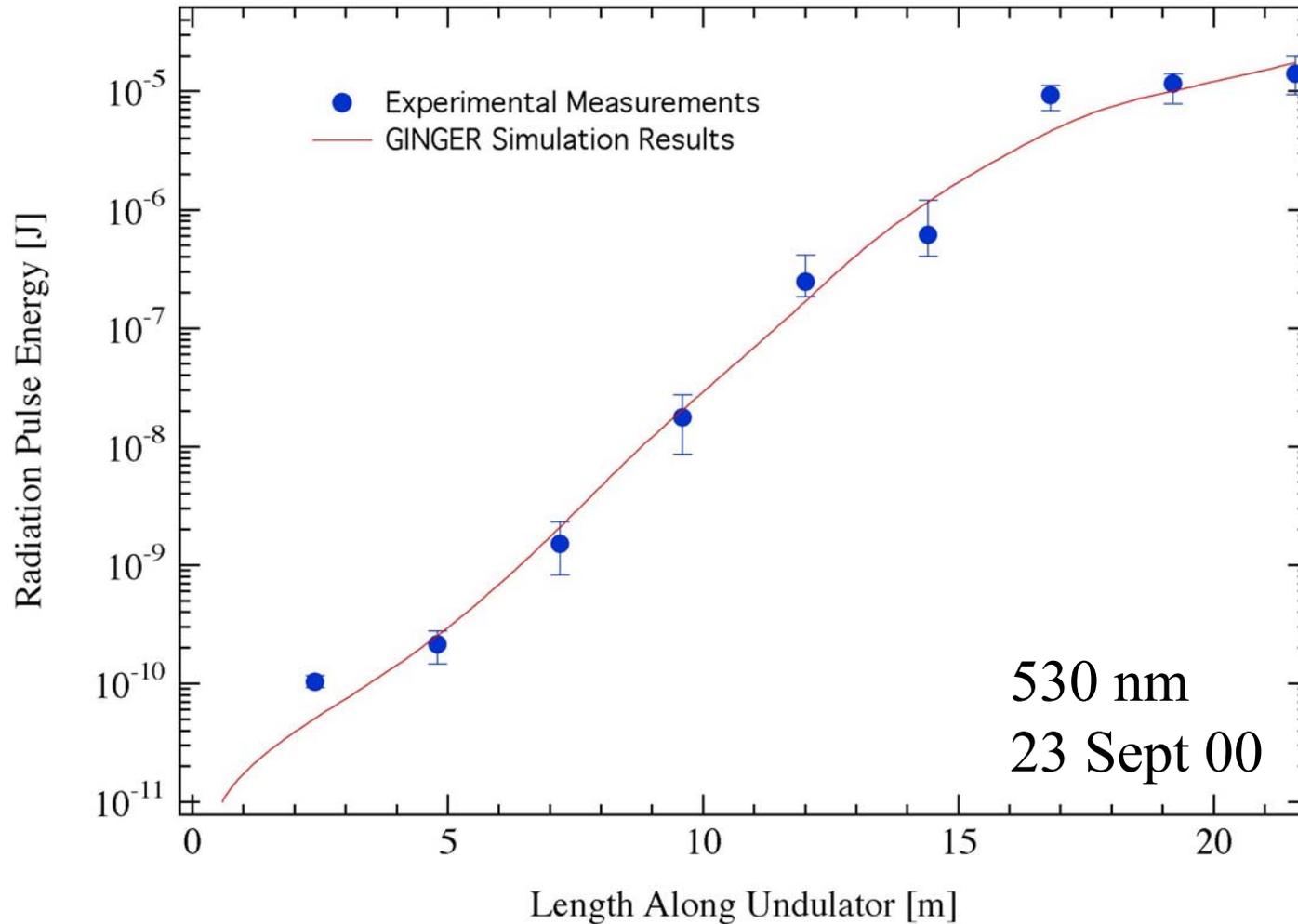


Trajectory & Matching Effects





Absolute Power





Conclusions

- The APS SASE-FEL saturated at
 - 530 nm, 23 September 2000; 2nd harmonic, March
 - 385 nm, 30 September 2000
 - 265 nm, March 2001
- Saturation at 530nm and 385 nm confirmed by rigorous statistical analysis
- So far, reasonable agreement between theory, simulation and experiment



Future Directions

- Shorter Wavelengths (of course!)
- More Characterization Experiments
 - better photocathode, more charge
 - capture section solenoid “emittance” knob
 - bunch compression “peak current” knob
- Pioneering User-Driven Experiments
- Exploration of 2nd-generation SASE-type devices
 - RAFEL
 - self-seeding
 - “afterburner”
 -?



For More Information...

Z-dependent spectral measurements

V. Sajaev, Fr-O-05

Nonlinear Harmonic Measurements

S.G. Biedron, Tu-P-07

Microbunching

A.H. Lumpkin, We-P-14, We-P-15

General

J.W. Lewellen et al, Tu-P-09